TIME-TAGGING ISSUE RESOLUTION TEAM
FINAL REPORT
(REVIEW DRAFT)

1. Introduction

The purpose of this paper is to capture and resolve the salient issues and to document adopted solution approaches related to assigning times to telemetry parameters, commands, and events. This report exploits the significant work that has been done in recent years which is cited in the references at the end of the report. In Section 2 we present the technical information related to time tagging processes and procedures. Section 3 describes how these processes fit into the Top-Down Architecture. Sections 4 and 5 provide a glossary of important terms and references to past related work.

2. Time Tagging Approach

This section examines the technical aspects of the time-tagging process. It has three sections for telemetry, commands, and events. Each of these areas is fully explored in terms of the cases and categories which imply specialized treatment to ensure that complete solutions are identified and all issues are resolved.

2.1 Telemetry

2.1.1 Basic Principles

<u>Telemetry Tagged with Spacecraft Time, TGT Ground Receipt Time, and CCS Receipt Time</u>: Spacecraft telemetry is received both in real time and as playbacks of recorded data. When Spacecraft Engineers analyze telemetry to monitor and maintain the spacecraft, they view the data in terms of the Spacecraft time since this represents the actual time events took place on board the spacecraft and corresponds most closely to the actual times of the telemetry measurements. Consequently, Spacecraft Time is computed and stored with the telemetry whenever possible. Since the playback data is received much later than the real-time data, it must be merged with the real-time data to fill in gaps and produce a single complete (to the greatest extent practical) stream. This merging will be performed based on Spacecraft Time.

Proper time tagging of the telemetry depends on proper detection of and compensation for several types of anomalies that can occur with the data. Both the TGT Ground Receipt Time and CCS Receipt Time are used to accomplish this. While time tagging is done initially in the FEP, the final precise and authoritative time tagging is done in Data Management during the merge processing so both times will be provided with the data. Another reason for having the CCS Receipt Time is to support the analysis of telemetry data recorded during simulation and test exercises (see Section 2.1.2 below).

<u>Single Algorithm for Converting VCC to UTC</u>: In the past, different systems (PRS, ESS, and PASS) have used different algorithms to calculate Spacecraft Time (expressed as UTC) from

Vehicle clock count (VCC). In CCS, we will use the same algorithm to convert VCC to Spacecraft Time for real-time (R/T) telemetry, Engineering Tape Recorder (ETR) playback, and Solid State Recorder (SSR) playback.

We will use the “PASS” algorithm which requires maintaining a set of clock correlation parameters: utc_0, vt_0, r_0, d_0. These parameters are updated weekly with the goal of maintaining the accuracy of the Spacecraft Time calculations to within 10 milliseconds.

Clock Correlation Parameter Updates: The clock correlation parameters used to convert VCC to UTC are updated weekly to maintain the desired 10 millisecond accuracy. The parameters are as follows:

utc_0, vt_0	UTC and VCC of a reference point
r_0	clock rate (approximately 125 milliseconds per count)
d_0	clock drift rate

Each week, data from the last 50 days is processed to produce the new set of clock correlation parameters. So in effect, a 50-day window that slides in one-week increments is used for this calculation. For each day in the 50-day window, roughly 40 minutes of real-time telemetry is retrieved. The correlation of VCC and UTC is determined by taking the TDRSS Ground Terminal (TGT) Ground Receipt Time (GRT) from the Nascom blocks and subtracting transmission delays. Transmission delays include buffering delays on HST, the propagation delay from HST to TDRS to TGT, internal TDRS delays, and the Return Channel Time Delay (RCTD) provided by TGT. The RCTD is the delay from the antenna to the MDM where the GRT time stamp is applied. The RCTD is received from TGT in an RCTD block sent at the end of each communications event (contact period) over the NCC line which also carries the ODMs.

It is noteworthy that using 4 Kb/s telemetry appears to produce clock correlation results that are systematically off by between 45 and 50 milliseconds from the results obtained using 32 Kb/s data. Since 4 Kb/s data produces a later time it is assumed to be incorrect because it presumably includes an unidentified delay.

The actual update, i.e. the point at which the new clock correlation parameters become effective, is performed during a Zone of Exclusion (ZOE). Currently in HSTOMS, the new clock correlation parameters are installed in the middle of the week so that Planning and Scheduling can use them for generation of the next set of command loads that will be uplinked. starting at the beginning of the following week. The new clock correlation parameters take effect immediately for the time tagging of incoming telemetry data as well.

Approximately once per year, on either June 30 or December 31, a leap second occurs to maintain the proper relationship between UTC and the Earth’s rotation. This leap second is accounted for along with the normal clock correlation update by subtracting 1 second from the utc_0 parameter. When a leap second is included, the new clock correlation parameters are installed in the middle of the week for use by Planning and Scheduling in generating the next set of command loads, but are not updated for use by telemetry time-tagging until those command loads actually take effect (during a ZOE at the beginning of the next week).

Procedures have been developed to ensure that clock correlation parameters of the proper epoch are used (see reference 7) for telemetry . This is especially important when merging real-time and recorder playback data near the boundary where a new set of clock correlation parameters takes effect, since the playback data may have been recorded before the boundary and not received on the ground until after the boundary.

UTC is available to all CCS processes: A common source of current UTC will be available to all CCS processes for time tagging events and commands. Current COTS technology is capable of providing this time source with accuracies of the order of a few microseconds and resolutions of 100 nanoseconds. The actual requirement has not been established, however, it is very unlikely that less than 0.1 millisecond accuracy is needed. The main issues remaining are design questions about how to provide this time to processors throughout CCS without incurring queuing delays.

2.1.2 Special Considerations

Real-time Telemetry: As real-time telemetry is received, the FEP calculates Spacecraft Time using the algorithm described in Section 2.1.1. Experience has shown that a variety of different data anomalies can occur that cause the algorithm to fail. To handle these cases, several data screening operations and time validation procedures are routinely performed by the software. The anomalies and time validation scheme are documented in Reference 10 and are listed below for convenience.

Anomalies that Occur with Real-Time Data

TGT Holdover -- TGT transmits the last few minor frames of a previous contact at the start of a new contact if no other spacecraft has been serviced (MDM buffers are cleared on spacecraft change).

CCS Receipt Time Delays -- Transmission or processing delays cause gap between TGT Receipt Time and CCS Receipt Time.

VCC corruption -- The VCC word in the telemetry is missing or contains errors.

UTC Failure -- The CCS Receipt Time was not properly recorded.

Corruption of attached TGT Ground Receipt Time -- The Nascom time stamp contains errors.

Extended poor quality data -- Poor link quality causes numerous errors in the data for an extended period of time.

Reference 10 also documents the procedures that have been incorporated into the PASS RTP code for identifying and correcting these errors as they are encountered during receipt of real-time data. These procedures are not 100% accurate, but do take care of the bulk of the problems, including the most severe problems.

ETR/SSR Playback: During Zones-of-Exclusion (ZOE), real-time telemetry is not available, however, the data may be recorded on-board and played back later. The playback data does not have GRT inserted into the Nascom blocks and CCS System Time bears no useful relationship to the Spacecraft Time. Therefore, time validation cannot be performed in the same manner as with real-time data. Typically, the recorder is started before loss-of-signal ends the real-time data flow so there is sufficient overlap of real-time and recorded data to match minor frames and synchronize the two streams. Also, corruption of the VCC value is possible, and so validation is required. The PASS TLMMAN software performs validation by comparing the VCC values for strings of between 10 and 20 minor frames.

Line Outage Recorder (LOR) Playback: Roughly 4 times per year, data sent from the White Sands TGT is lost or garbled and must be re-sent. TGT routinely records all data and maintains the data for 24 hours. Within the 24-hour retention period, TGT will playback the data upon request, however, the GRT time stamp will reflect the time it was played back rather than the time it was recorded. This is because the time stamp is attached by the MDM when the data is blocked and the LOR records the data before it goes through the MDM. Thus, GRT cannot be used for time validation with LOR playback data.

GSTDN Playback: This is similar in concept to LOR playback except that it occurs very infrequently (approximately once every 5 years). It will be assumed that whatever provisions are made for time-tagging LOR playback will work for GSTDN playback as well. If this turns out to be false, no further provisions will be made because it is so infrequent.

FEP Playback: Occasionally, raw data received and recorded by the CCS FEP may be played back through the FEP to observe a sequence of events in an effort to diagnose an anomaly. This could be done using a secondary processing string so that the data is kept separate and does not enter the archive a second time. An FEP replay might also be performed to fill gaps caused by faulty data that could not be successfully processed by the FEP initially or data that was not captured by Data Management due to equipment failure. FEP replay can also be used to conduct local tests and simulations. Data that is played back by the FEP will have as the CCS Receipt Time the time that it was originally recorded, not the time that it was played back.

Memory Dumps: Memory dumps of the NSSC-1, DF-224, 486 Microprocessor, and SI Microprocessors are performed occasionally and must be extracted from the downlink data and provided to the appropriate personnel. Also, there are NSSC-1 and 486 status buffers that are readout periodically. The table below identifies the types of memory dumps, the link that carries them, and to whom the data is provided.

Type of Memory Dump	Link	Destination
NSSC-1 Memory Dump	SSA 1Mb/s	Flight Ops; Flight SW Eng
DF-224 Memory Dump	MA-I 4Kb/s	Flight Ops; Flight SW Eng
SI Microprocessor (except WF/PC)	SSA 1Mb/s	Flight SW Eng; Science Institute
WF/PC Microprocessor	Engineering Telemetry	Flight SW Eng; Science Institute
NSSC-1 Status Buffers	MA-I 4Kb/s	Flight Ops; Flight SW Eng

486 Status Buffers	(MA-I 4Kb/s)?	Flight Ops; Flight SW Eng

Memory dumps are time-stamped with the CCS Receipt Time and are packaged as separate files for delivery to the designated recipient.

Simulations and Testing: During simulation and testing activities, data sources with pseudo-spacecraft time or no spacecraft time may be used. Personnel participating in the tests, including representatives of external interfaces, will note in their logbooks events for which they will want to later examine relevant data. These notes will typically refer to standard wall clock time rather than pseudo-spacecraft time, so requests for data retrievals will typically specify the wall-clock time. This means that CCS System Time will need to be recorded along with spacecraft time. If the test is run many times, the resulting data sets may span the same range of spacecraft times and different wall clock times reflecting when the test was actually run. Also, provision must be made to keep test and simulation data separate from the operational data in the archive.

4 Kb/s Telemetry: There are no particular time-tagging considerations associated with 4 Kb/s telemetry. Note that 4 Kb/s data is, when used for clock correlation derivation, produces a later time than with 32 Kb/s (see Section 2.1.1 under Clock Correlation Parameter Updates).

32 Kb/s Telemetry: The 32 Kb/s telemetry arrives in minor frames at the rate of 20 per second or every 50 ms. Since the vehicle clock increments approximately every 125 ms, alternately two or three adjacent minor frames have the vehicle clock count. The position of the 3-2 pattern in the data stream can be determined by knowing its relationship to the minor frame counter and is used to calculate the spacecraft time for each minor frame. Some of the attitude sensor parameters are super-commutated in that they appear twice in each minor frame to produce data samples at the rate of 40 hertz. The first sample in each minor frame is to be time-tagged with the Spacecraft Time for that minor frame and the second sample is time-tagged one-half a frame (approximately 25 ms) later.

D/E Format: Format D or E data is generated when the spacecraft is in safemode. In these formats, the OBC is not running and so the vehicle clock count is not read into the telemetry and, consequently, is not available for time tagging. Real-time D/E will be time-tagged using either TGT Ground Receipt Time or CCS Receipt Time adjusted for propagation delays. It doesn't matter from an accuracy perspective whether TGT or CCS Time is used. Currently, HSTOMS uses its equivalent of CCS Time, however, when Nascom makes the transition to the UDP/IP protocol, the routing and queuing delays may require utilization of TGT (GRT) Time.

ETR/SSR playback of D/E data cannot be time-tagged in this way because GRT does not reflect the time the data was generated by the spacecraft. When multiple segments of telemetry are recorded and then dumped as one playback, it is very difficult (labor-intensive manual process) to tell where one segment ends and the next begins. The only circumstance in which playback D/E data can be easily time-tagged is when the start time of a recorded segment can be determined. This might be true, for example, if the ETR were positioned at the beginning of a zone prior to recording a segment.

In general, playback D/E data need not be time-tagged and merged for permanent archive. If the spacecraft goes into safemode during a ZOE, however, it will be evident in the playback when the format D/E was recorded because it directly follows a regular format. This data is of primary interest and should be time-tagged and provided to the SEs.

Some or all of a particular dump may be time-tagged if requested by SEs, however, this is a labor-intensive manual process. Appropriately planned operational procedures that properly configure the ETR or SSR could produce data that can be time-tagged in a straightforward manner (see Reference 13).

2.1.3 Issues

The following issues will require further discussion or consideration.

1) Coordination of Clock Correlation Updates with Planning and Scheduling -- Now that Planning and Scheduling is a separate operational unit from CCS, the procedures for generation and installation of clock correlation parameters must be coordinated between the two parties.

2.2 Commands

No particularly demanding timing issues related to commanding are known. Commands will be time-tagged with the time the command is processed by CCS expressed as UTC obtained from a common CCS System Time process.

2.3 CCS Events

Events will be time-tagged with the time the event is processed by CCS expressed as UTC obtained from a common CCS System Time process.

3. Functional Allocation

The following table lists the principal time-tagging functions, identifies these functions in terms of their inputs and outputs, and relates them to the CCS Top-Down Architecture. Bold items in the INPUT and OUTPUT columns are in the TDA Data Dictionary.

FUNCTION	TDA REFERENCE	INPUTS	OUTPUTS
TIME-TAGGING	Convert Engineering Data (1.6)	**HST Downlink**	**Converted FE Data** Containing UTC
Data Screening	"	"	
Data Trimming	"	"	Discarded Minor Frames
Time Validation	"	"	Time Quality Flag
UTC Calculation	"	Clock Correlation Parameters Vehicle Clock Count	UTC Value
MERGING	Ingest Stream Data (4.1)	**FE Data**	**Stream Data Files**
CLOCK CORRELATION UPDATE	Perform Analysis and Trending (3.5)	Return Channel Time Delay History Ephemeris Data 50-day clock history	New Clock Correlation Parameters

4. Glossary

Ground Receipt Time (GRT) -- The GRT time is inserted by Nascom at the TDRSS Ground Terminal (TGT). Based on the UTC time standard, it represents the time that the telemetry data was buffered in Multiplexor-Demultiplexor (MDM) by Nascom. For real-time data, this time can differ from the precise time that an event occurred on the spacecraft by the time (a fraction of a second) that it takes the spacecraft to collect the information for downlinking and the propagation delay associated with transmitting the data to the ground via the TDRSS satellite. For data recorded on the Engineering Tape Recorder (ETR) and subsequently played back, no Ground Receipt Time is applied to the data. Occasionally, the last few minor frames of a contact period are held over at TGT in the MDM buffers before the time stamp is applied and are then sent to GSFC at the beginning of the next contact period with incorrect GRT inserted. Handling of this data is discussed in Reference 10.

Vehicle Clock Count -- Each telemetry minor frame for all formats (except for D and E formats) contains a readout of the Vehicle Clock, a 32-bit counter on board the spacecraft. This counter represents the number of clock ticks which have occurred since the on-board counter was reset.and the readout is referred to as the Vehicle Clock Count. The clock rate is nominally 8 counts per second (125 ms per clock count). Measurements of the precise clock rate and drift rate are made routinely and are used to perform the conversion from Vehicle Clock Count to a UTC value which is called Spacecraft Time.

Spacecraft Time -- Spacecraft Time refers to the time expressed as UTC which is calculated from the Vehicle Clock Count for each minor frame. This is used to represent the nominal time that the information from the telemetry sensors on-board the spacecraft was strobed into the minor frame, although no attempt is made to identify exactly when within a minor frame any given mnemonic was actually sampled. For 32 Kb/s data, information is strobed twice in each minor frame and data in the second half is assigned a Spacecraft Time 25 ms later than the first half. All data requests to the Data Management Archive software will be based on Spacecraft Time. Spacecraft time is calculated from the Vehicle Clock Count embedded in every telemetry minor frame, using the clock correlation parameters.

CCS Receipt Time -- The CCS Receipt Time is the CCS System Time attached to the telemetry data when it is received by the FEP.

CCS System Time -- This is the UTC time available to all CCS processes for use in time-tagging events, commands, and received data. It is sometimes referred to as "wall clock" time. The reliability, accuracy, precision, and method of generation and distribution are TBD.

Universal Time Coordinated (UTC) -- The official civil time as maintained by the coordinated national time keeping services. See Reference 16 for details. UTC is referenced to the same time zone as Greenwich Mean Time.

5. References

1) ICD 53, Revision A; FACC-TR3804; November, 1985.

2) “White Paper on Engineering Support System (ESS) Time References”; January 17, 1990.

3) Memo: To M. Nadelman; from G. Welter; “HST Clock Correlation Timing Accuracy”; CSC ref: 20:0793-001-GW; August 3, 1993.

4) Memo: To W. Ochs; from E. Greville; “Processing and Archiving of Format D/E Engineering Data”; HSTOMS SEB; April 6, 1994.

5) Memo: To Carolyn Dent; from Jim Fessler; “Analysis of PASS Spacecraft Time Calculation Within the ESS”; LORAL 0082SAMS94; April 27, 1994.

6) Memo: To J. Hodges; from E. Greville; “Processing and Archiving of Format D/E Engineering Data”; HSTOMS SEB; May 9, 1994.

7) Memo: To D. Derrick; from G. Welter, K. Underwood; “Duplicate Minor Frames in AEDP-Generated Data Products”; CSC ref: 50:1294-002-GW; January 15, 1995.

8) Memo: To D. Derrick; from G. Welter; “Automatic Selection of TLMMAN Data Sanity Window Limits”; CSC ref: 50:0295-001-GW; March 6, 1995.

9) Memo: To D. Derrick; from G. Welter; “ETR vs. Real-time Data Priority in Duplicate Minor Frame Resolution”; CSC ref: 50:0395-002-GW; March 16, 1995.

10) Memo: To D. Derrick; from G. Welter; “Real-Time Telemetry Data Time Validation”; CSC ref: 50:0495-001-GW-r2; May 23, 1995.

11) HSTOMS CCR 1958; “Real-time Telemetry Validation”; G. Welter, June 29, 1995.

12) Specification sheet for bc637VME/bc357VXI GPS Satellite Receiver; Datum Inc. Bancomm Division; 6781 Via Del Oro, San Jose, CA 95119; (408) 578-4161.

13) Memo: To E. Greville; from G. Welter; “Technical Issue 31 - Time Tagging of DE Data”; CSC; April 29, 1996.

14) PASSOPS S/C Clock Correlation Procedures, December 1995.

15) Engineering Memorandum, “Relationship of UTC with Spacecraft Time Word for Ground Processing”, EM # DMS 225A, August 21, 1989, Revised November 30, 1989.

16) Explanatory Supplement to the Astronomical Almanac, Prepared by the Nautical Almanac Office of the US Naval Observatory, 1992, University Science Books, Mill Valley CA.